PACIFIC NORTHWEST PROVINCE

by Kenneth A. Piper

LOCATION

The Pacific Northwest province extends from Cape Flattery, Washington, to Cape Mendocino, California, a distance of about 550 miles. This Federal offshore assessment province is bounded on the east by the 3-mile line and on the west by the base of the continental slope (fig. 13).

GEOLOGIC SETTING

The province is a convergent margin characterized by a relatively narrow continental shelf and slope and a trench complex to the west. The high rate of sedimentation in this area has resulted in a thick Neogene sedimentary sequence on the shelf and a poorly defined bathymetric trench. The oceanic plate

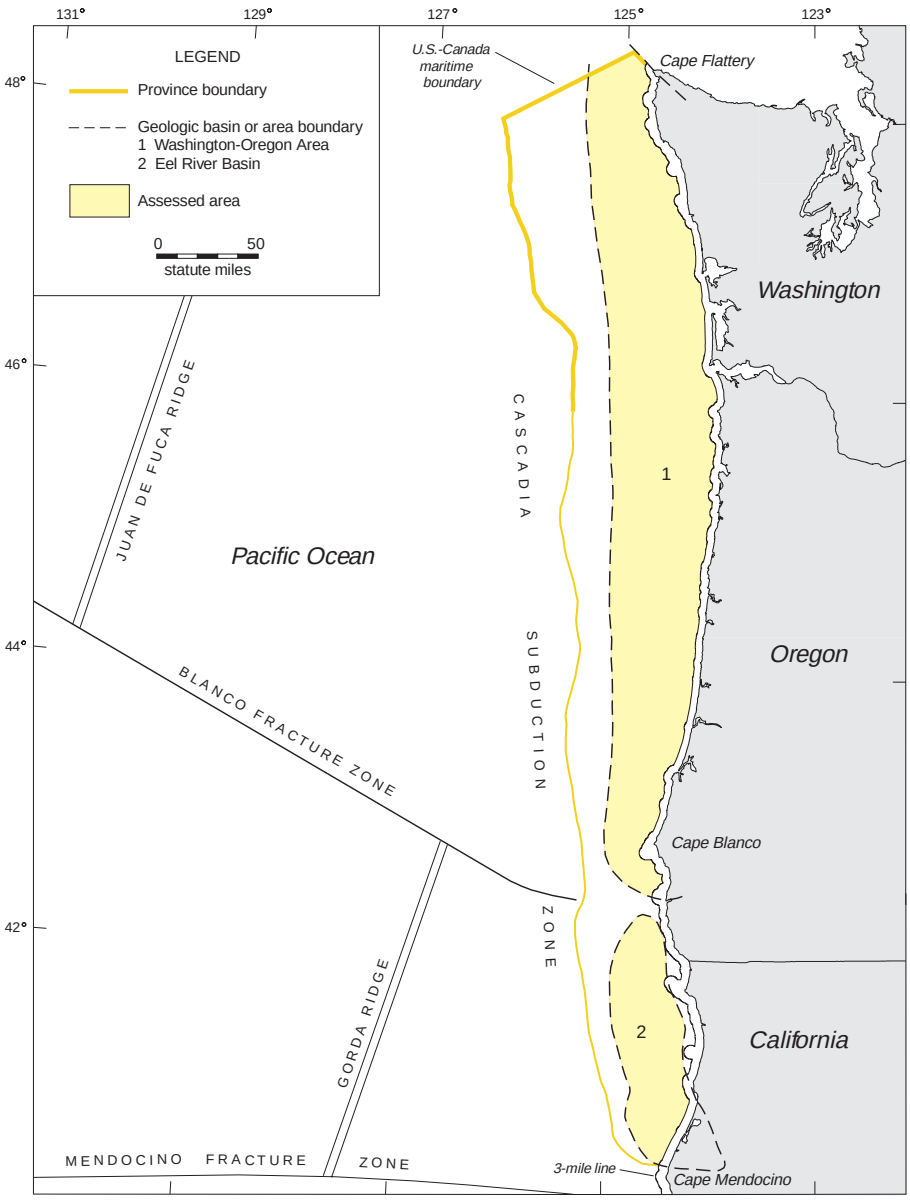


Figure 13. *Map of the Pacific Northwest province showing geologic basins and areas, assessed areas, and tectonic features.*

Table 5. *Estimates of undiscovered conventionally recoverable oil and gas resources in the Pacific Northwest province as of January 1, 1995, by assessment area. All estimates are risked values. The low, mean, and high estimates correspond to the 95th-percentile, mean, and 5th-percentile values of a probabilitydistribution, respectively. Percentile values are not additive; some total mean values may not equal the sum of the component values due to independent rounding.*

Assessment Area	Oil (Bbbl)			Gas (Tcf)			BOE (Bbbl)		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Washington-Oregon Area	0.14	0.36	0.69	0.95	2.30	4.28	0.32	0.76	1.42
Eel River Basin	0.03	0.05	0.08	1.06	1.61	2.32	0.23	0.34	0.49
Total Province	*0.19*	*0.41*	*0.75*	*2.34*	*3.91*	*6.03*	*0.61*	*1.11*	*1.79*

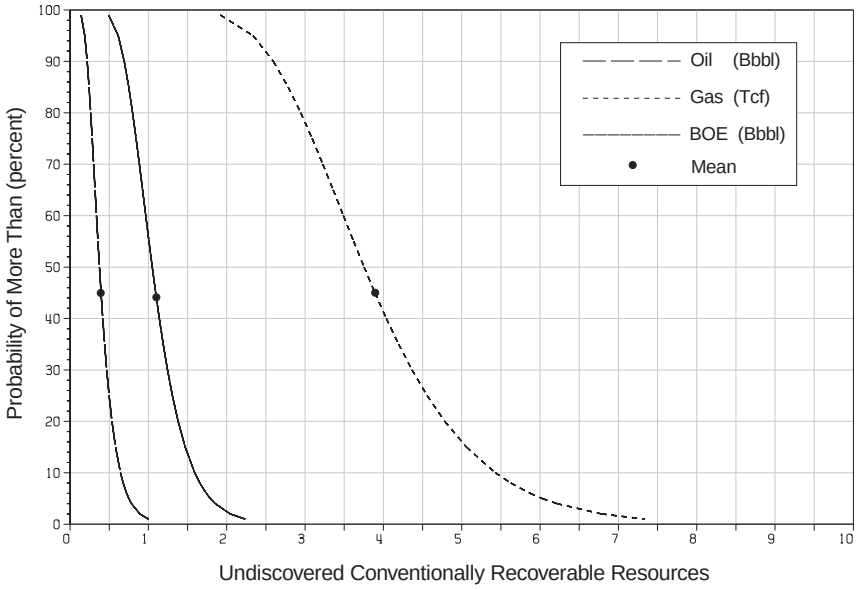


Figure 14. *Cumulative probability plot of estimated undiscovered conventionally recoverable resources of the Pacific Northwest province.*

on the west is divided into two subplates separated by the Blanco fracture zone offshore Cape Blanco, Oregon. This boundary divides the province into a northern group of poorly defined subbasins, which are collectively referred to as the Washington-Oregon area, and the Eel River basin, which extends south to the Mendocino fracture zone offshore Cape Mendocino. The two assessment areas (i.e., Washington-Oregon area and Eel River basin) of the province and the petroleum geologic plays defined within them are described following this province summary.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of the total volume of undiscovered conventionally recoverable resources in the province have been developed by statistically aggregating the constituent assessment area estimates. As a result of this assessment, the total volume of undiscovered conventionally recoverable resources in the Pacific Northwest province is estimated to be 410 MMbbl of oil (including oil and condensate) and 3.91 Tcf of gas (including associated and nonassociated gas) (mean estimates). The low, mean, and high estimates of resources in the province are listed in table 5 and illustrated in figure 14.

Table 6. *Estimates of undiscovered economically recoverable oil and gas resources in the Pacific Northwest province as of January 1, 1995 for three economic scenarios, by assessment area. All estimates are risked mean values. The $18-per-barrel scenario is based on prices of $18 per bbl of oil and $2.11 per Mcf of gas; the $25-per-barrel scenario is based on prices of $25 per bbl of oil and $2.94 per Mcf of gas; the $50-per-barrel scenario is based on prices of $50 per barrel of oil and $5.87 per Mcf of gas. Some total values may not equal the sum of the component values due to independent rounding.*

Assessment Area	$18-per-barrel Scenario			$25-per-barrel Scenario			$50-per-barrel Scenario		
	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)
Washington-Oregon Area	0.09	0.65	0.21	0.13	0.90	0.29	0.20	1.37	0.44
Eel River Basin	<0.01	0.28	0.06	0.01	0.42	0.09	0.03	0.77	0.16
Total Province	*0.10*	*0.93*	*0.27*	*0.14*	*1.32*	*0.38*	*0.22*	*2.13*	*0.60*

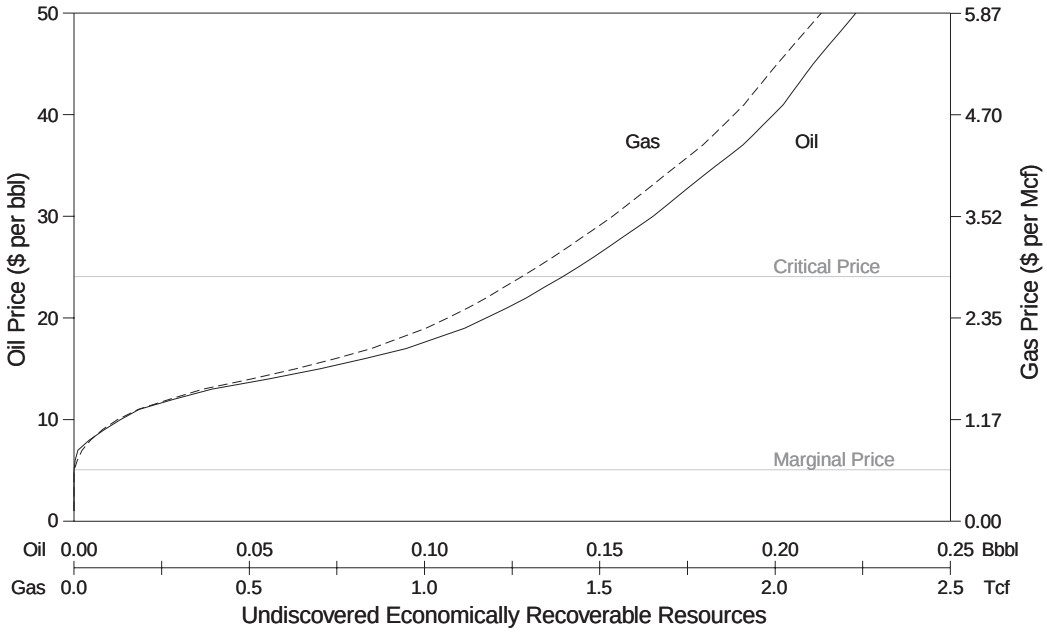


Figure 15. *Price-supply plot of estimated undiscovered economically recoverable resources of the Pacific Northwest province.*

Undiscovered Economically Recoverable Resources

Estimates of the total volume of undiscovered conventionally recoverable resources in the province that may be economically recoverable under various economic scenarios have been developed by statistically aggregating the constituent assessment area estimates. As a result of this assessment, 104 MMbbl of oil (including oil and condensate) and 932 Bcf of gas (including associated and nonassociated gas) are estimated to be economically recoverable from the Pacific Northwest province under economic conditions existing as of this assessment (i.e., the $18-per-barrel economic scenario) (table 6). Larger volumes of resources are expected to be economically recoverable under increasingly favorable economic conditions (fig. 15).

Total Resource Endowment

No accumulations of resources have been discovered in the province. Therefore, the aforementioned estimates of undiscovered conventionally recoverable resources compose the estimated total resource endowment of the province.

WASHINGTON-OREGON AREA

by Kenneth A. Piper

LOCATION

The Washington-Oregon assessment area is the northern subarea of the Pacific Northwest province (fig. 13). This Federal offshore (i.e., seaward of the 3-mile line) area extends from Cape Flattery, Washington, to "Retirement ridge" (an informally named structural high) south of Cape Blanco, Oregon, a distance of about 400 miles (fig. 16). The area is about 30 to 50 miles wide and encompasses about 18,000 square miles. Water depth in the area ranges from about 100 feet on Nehalem Bank to about 1,200 feet locally along the shelf-slope boundary. Interpretation of a coarse grid of seismic-reflection profiles identified six Neogene depocenters or subbasins (Webster, 1985; Cranswick and Piper, 1992). The boundaries of the subbasins delineated by isochore mapping generally conform with basin outlines published by other investigators.

GEOLOGIC SETTING

The deepest rocks penetrated by offshore wells include Paleocene to Miocene melange (fig. 17). The

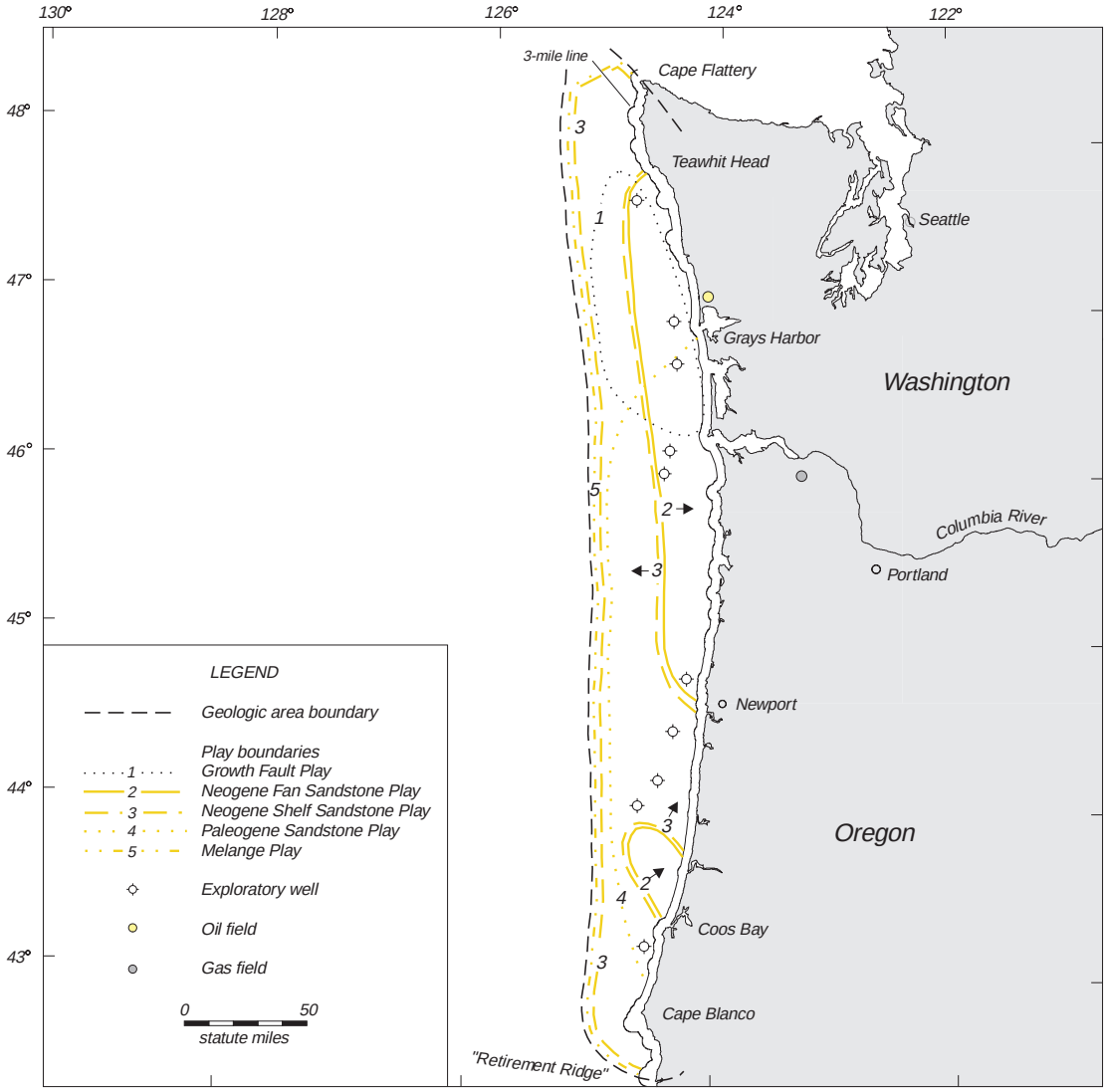
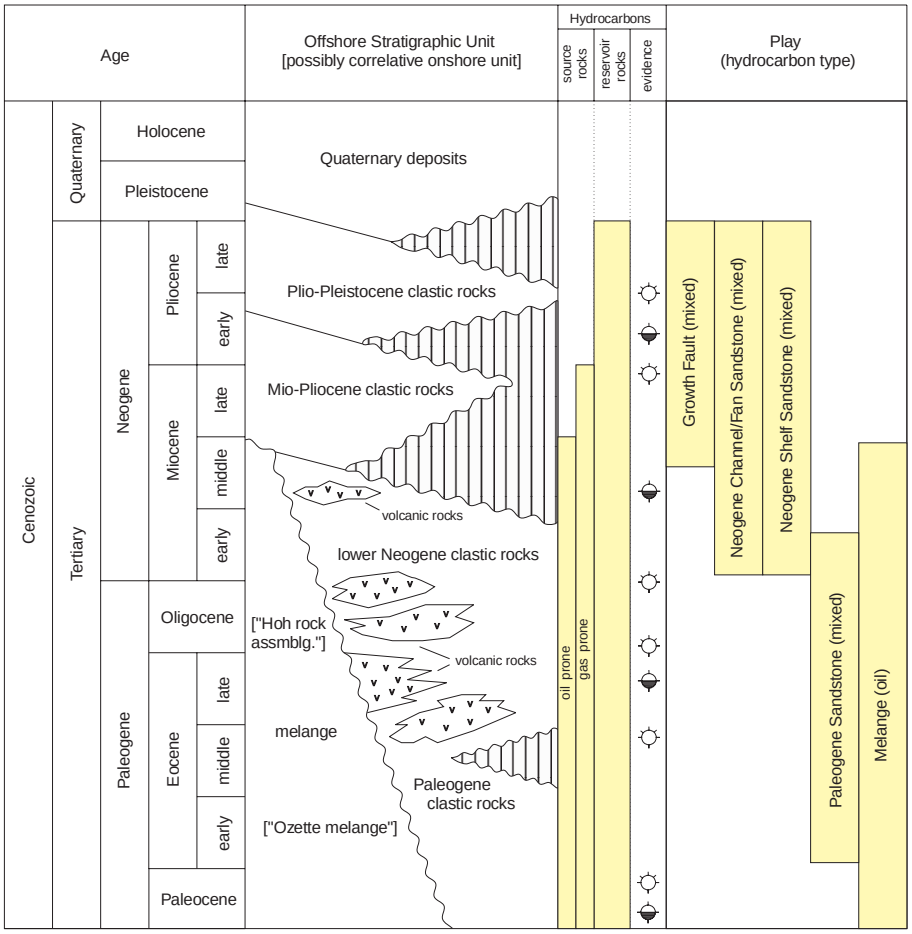


Figure 16. *Map of the Washington-Oregon assessment area showing petroleum geologic plays, wells, and fields.*



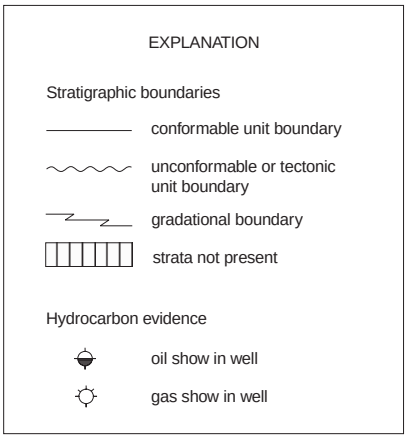


Figure 17. *Stratigraphic column of the Washington-Oregon assessment area showing stratigraphic units, hydrocarbon attributes, and petroleum geologic plays defined for this assessment.*

upper part of this section to at least the depth penetrated by the wells is considered to be largely olistostrome and turbidite deposition in trench and slope environments overlying the subduction complex. Onshore, lithologically correlative rocks exist in the Olympic Peninsula of Washington (Palmer and Lingley, 1989). In the eastern part of the area south of Grays Harbor, Washington, an assemblage of possibly allochthonous, Paleocene(?) to Eocene tholeiitic volcanic rocks overlies the melange (Snavely and Wells, 1984; Wells and others, 1984; Snavely, 1987). Above this lies a sequence of Paleocene to Holocene clastic strata, which attains a thickness in excess of 20,000 feet offshore central Oregon. North of Grays Harbor and along the western margin of the entire area, Neogene strata directly overlie the melange.

Most major structures are north- to northwest-trending and include compressional folds and faults, right-lateral strike-slip faults, and extensional faults. Large-scale extensional growth faults are a dominant feature offshore Washington, and shale diapirs are present offshore Washington and Oregon (Piper, 1994; Piper and others, 1995).

The rock record suggests a westward migration of subduction (Kulm and Fowler, 1974; Snavely, 1987; Snavely and others, 1988). Paleogene deposition occurred in the eastern part of the area; Neogene strata directly overlie the subduction complex to the west. The upper Tertiary accretionary complex developed adjacent to the older subduction zone and forearc basins developed along the modern continental shelf. The growth faulting, diapirism, and other extensional features suggest westward extension of the upper plate concurrent with rapid sedimentation since early Miocene time (Piper, 1994).

EXPLORATION

Twelve exploratory wells were drilled at 10 sites in the 1960's. Also, three Deep Sea Drilling Project (DSDP) coreholes were drilled offshore Oregon in 1971 (Kulm and others, 1973). Hydrocarbon shows were encountered at eight of the exploratory well sites. Drill-stem tests on two of the wells, OCS-P 0150 #1 (southwest of Grays Harbor, Washington) and OCS-P 0112 #1 (southwest of Coos Bay, Oregon) yielded gas at rates of 10 to 26, and 49 to 68 Mcf

per day, respectively (Zieglar and Cassell, 1978). A small oil field in the Ocean City area, onshore north of Grays Harbor, Washington, produced about 12 Mbbl of high-gravity (38.9 °API) oil and about 6.5 MMcf of gas from 1957 to 1962; several other wells in the area encountered subcommercial quantities of oil and gas (Braislin and others, 1971; McFarland, 1983; Palmer and Lingley, 1989). Oil shows from wells near Grays Harbor and the Columbia River (OCS-P 0155 #1 and OCS-P 0072 #1, respectively) indicate the presence of high-gravity oil comparable with that produced in the Ocean City area (Zieglar and Cassell, 1978). Continuing production at Mist gas field onshore, west of Portland, Oregon, has yielded about 56 Bcf of gas as of January 1, 1995 (Dan Wermiel, Oregon Department of Geology and Mineral Industries, oral commun., 1995). Stratigraphic and paleontologic data from the offshore wells and a relatively sparse grid of seismic-reflection data are the bases for interpretation of the offshore geology.

PLAYS

For this assessment, five petroleum geologic plays were defined based on trapping and reservoir rock characteristics (figs. 16 and 17). Three Neogene plays, one Paleogene play, and a melange play were so defined. The plays are described following this assessment area summary. Rocks which are equivalent to rocks of these plays exist onshore and in the state offshore areas. Some of these rock units are included in plays which have been assessed within the Western Oregon-Washington province by the USGS (Johnson and Tennyson, 1995).

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Play-specific estimates of undiscovered conventionally recoverable resources have been developed using the subjective assessment method, and these estimates have been statistically aggregated to estimate the total volume of resources in the area. Select data used to develop the resource estimates are shown in appendix C.

As a result of this assessment, the total volume of undiscovered conventionally recoverable resources in the Washington-Oregon assessment area is estimated to be 355 MMbbl of oil (including oil and condensate) and 2.30 Tcf of gas (including associated and nonassociated gas) (mean estimates). This volume may exist in 185 fields with sizes ranging from approximately 10 Mbbl to 125 MMbbl of combined oil-equivalent resources (fig. 18). The low, mean, and high estimates of resources in the area are listed in table 7 and illustrated in figure 19.

Undiscovered Economically Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the assessment area that may be economically recoverable under various economic scenarios have been developed using the economic assessment method. Select data used to develop the resource estimates are shown in appendix D.

As a result of this assessment, 95 MMbbl of oil (including oil and condensate) and 652 Bcf of gas (including associated and nonassociated gas) are estimated to be economically recoverable from the Washington-Oregon assessment area under economic conditions existing as of this assessment

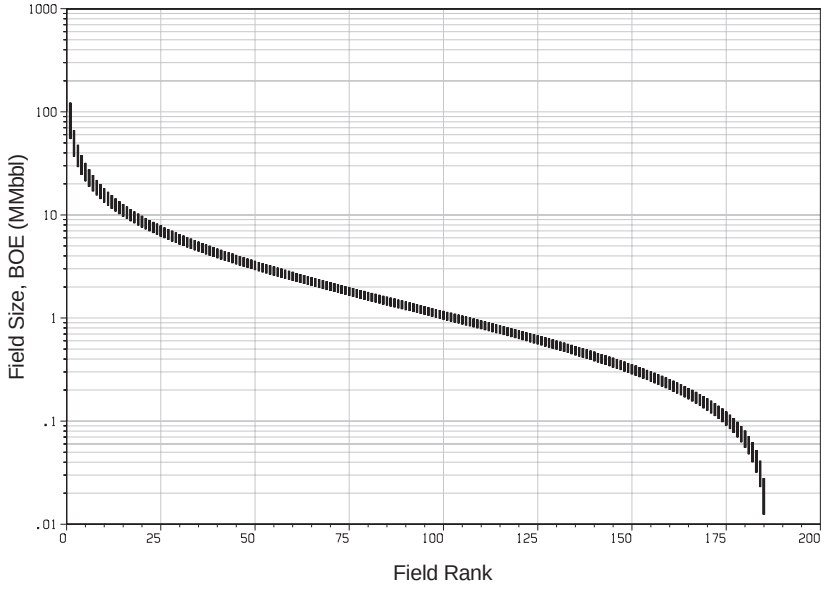


Figure 18. *Field-size rank plot of estimated undiscovered conventionally recoverable resources of the Washington-Oregon assessment area. Sizes of undiscovered fields are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

Table 7. *Estimates of undiscovered conventionally recoverable oil and gas resources in the Washington-Oregon assessment area as of January 1, 1995, by play. All estimates are risked values. The low, mean, and high estimates correspond to the 95th-percentile, mean, and 5th-percentile values of a probability distribution, respectively. Percentile values are not additive; some total mean values may not equal the sum of the component values due to independent rounding.*

Play	Oil (MMbbl)			Gas (Bcf)			BOE (MMbbl)		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Growth Fault	0	110	283	0	450	1,341	0	190	502
Neogene Fan Sandstone	0	98	207	0	882	1,854	0	255	522
Neogene Shelf Sandstone	0	138	287	0	596	1,303	0	244	510
Paleogene Sandstone	0	9	23	0	372	753	0	75	151
Melange	not assessed								
Total Assessment Area	*136*	*355*	*687*	*950*	*2,300*	*4,280*	*316*	*765*	*1,423*

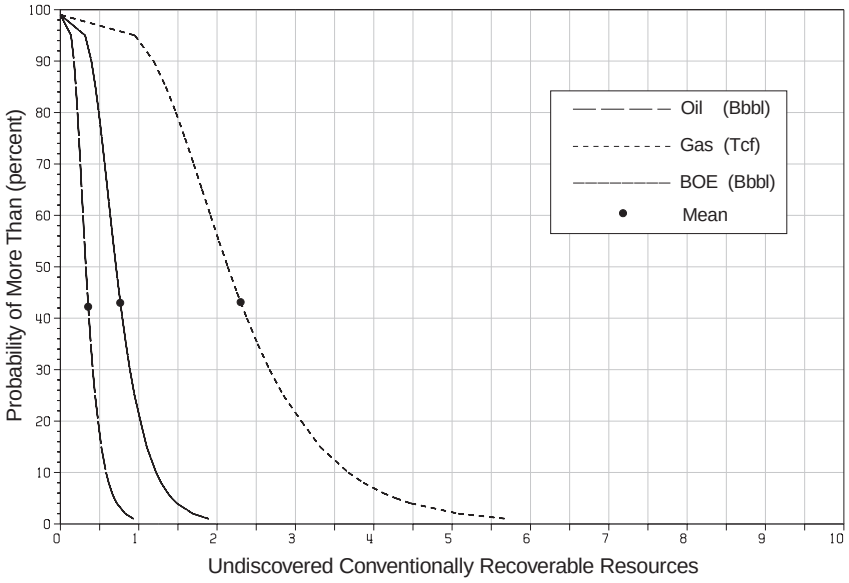


Figure 19. *Cumulative probability plot of estimated undiscovered conventionally recoverable resources of the Washington-Oregon assessment area.*

(i.e., the $18-per-barrel economic scenario) (table 8). Larger volumes of resources are expected to be economically recoverable under increasingly favorable economic conditions (fig. 20).

Total Resource Endowment

No accumulations of resources have been discovered in the Washington-Oregon assessment area. Therefore, the aforementioned estimates of undiscovered conventionally recoverable resources compose the estimated total resource endowment of the area.

ACKNOWLEDGMENTS

The following individuals provided information, insight, and suggestions that greatly improved the quality of this assessment of the Washington-Oregon assessment area: Sam Johnson and Lynn Tennyson (U.S. Geological Survey), Bill Lingley (Washington State Department of Natural Resources), Dan Wermiel and Dennis Olmstead (Oregon Department of Geology and Mineral Industries), and Ed Edwards and Ron Heck (Heck & Associates). Micropaleontologic interpretation of offshore well samples by Scott Drewry (Minerals Management Service) was of key importance in establishing the offshore stratigraphic correlations. The Northwest Energy Association (formerly Northwest Petroleum Association) also provided assistance and hosted a public workshop in support of this assessment.

ADDITIONAL REFERENCE

McLean and Wiley, 1987

Table 8. *Estimates of undiscovered economically recoverable oil and gas resources in the Washington-Oregon assessment area as of January 1, 1995, by economic scenario. All estimates are risked mean values. The $18-per-barrel scenario is based on prices of $18 per bbl of oil and $2.11 per Mcf of gas; the $25-per-barrel scenario is based on prices of $25 per bbl of oil and $2.94 per Mcf of gas; the $50-per-barrel scenario is based on prices of $50 per barrel of oil and $5.87 per Mcf of gas.*

Economic Scenario	Oil (MMbbl)	Gas (Bcf)	BOE (MMbbl)
$18 per barrel	95	652	211
$25 per barrel	131	903	291
$50 per barrel	198	1,366	441

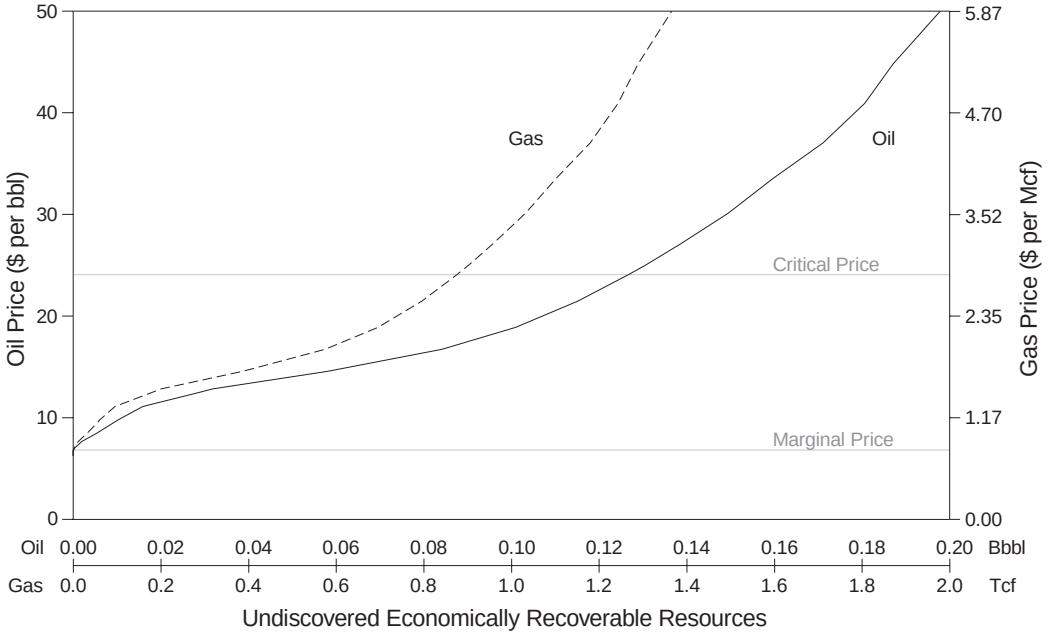


Figure 20. *Price-supply plot of estimated undiscovered economically recoverable resources of the Washington-Oregon assessment area.*

GROWTH FAULT PLAY

PLAY DEFINITION

The Growth Fault play of the Washington-Oregon assessment area is defined to include accumulations of oil and gas in Miocene and Pliocene sandstones deposited in deltaic and fan systems on the shelf and now incorporated in traps associated with growth faults. It is a conceptual play because no traps within this play have been tested. The play extends from Teawhit Head, Washington, to the Washington-Oregon border (Columbia River) and encompasses an area of about 3,400 square miles (fig. 16). It is defined on the basis of trap type.

The Growth Fault play includes rocks that are equivalent to those of the Neogene Fan Sandstone play and the Neogene Shelf Sandstone play; it is differentiated from those plays on the basis of expected trap characteristics and the increased likelihood of vertically stacked traps. Hydrocarbon accumulations may occur to about 8,000 feet below the seafloor.

PETROLEUM GEOLOGIC CHARACTERISTICS

The primary hydrocarbon source is Miocene and older melange, which, over most of the play area, directly underlies the Neogene sedimentary section (fig. 17). Based on seeps and past production from probable equivalent rocks in the western Olympic Peninsula, Washington (Palmer and Lingley, 1989), and near Eel River basin, California (Vander Leck, 1921; MacGinitie, 1943; California Division of Oil and Gas, 1960; 1982), these are expected to be primarily a source of high-gravity oil. In the southernmost one-fifth of the area, Eocene to Oligocene shales are present above the melange and are a possible gas source. Geothermal gradients (Snavely, 1987; Palmer and Lingley, 1989) suggest that source rocks are likely to be mature for oil generation at burial depths greater than about 10,000 to 12,000 feet. The Paleogene sedimentary rocks are not expected to exist below 10,000 feet within the play area, and kerogen type indicates that they are gas prone; they are, therefore, considered primarily a source of nonassociated gas.

Potential reservoirs are expected to be of good to fair quality. They consist of sandstones and siltstones deposited in shelf and slope environments where high rates of sedimentation upon an unstable trench/slope complex resulted in active growth faulting (Piper, 1994; Piper and others, 1995). Growth faulting produces much greater sediment thickness on the downthrown side relative to the upthrown side of the fault. The high sedimentation rate combined with the faulting is expected to have resulted in greater reservoir thicknesses compared to other plays and in increased potential for stacked reservoirs.

Potential traps include anticlinal rollovers on both sides of the faults and traps against the fault surface. The fault-related anticlines are generally larger and are the more important trap type; the faults may be conduits for escape of hydrocarbons rather than trapping them.

EXPLORATION

Although growth faults are abundant within the play area, no exploratory wells have been drilled into traps associated with them. However, there are indications of oil and gas in rocks considered to be likely source rocks for this play. In petroleum provinces elsewhere in the world, growth faults are considered important targets.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the play have been developed using the subjective assessment method. Select data used to develop the resource estimates are shown in appendix C.

The play was modeled as a mixed-commodity (oil with associated gas, and nonassociated gas with condensate) play on the basis of expected source rocks. Potential pools in the northern part of the play are considered oil pools because the melange is the primary source. In the southern part, nonassociated gas sourced from the Paleogene section is considered to be a secondary commodity. Because of the low temperature gradient, oil generation is expected only where source rocks are present at burial depths greater than 10,000 feet. The Paleogene section is thin where present within the play area and is too shallow for oil generation. Overall, pools in the play were modeled as primarily oil; nonassociated gas was modeled as a component of 30 percent of the expected pools. Previous seismic mapping of the area—based on a relatively sparse seismic data grid—was revised for the assessment because growth faults had not been recognized. The estimated areas and number of prospects are based on that revision. Reservoir parameter distributions (e.g., recovery factors) were based largely on data from fields in California; however, the net-pay thickness distribution was increased to account for the thicker accumulations expected with growth faults.

As a result of this assessment, the play is estimated to contain 110 MMbbl of oil (including oil and condensate) and 450 Bcf of gas (including associated and nonassociated gas) (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 46 pools with sizes ranging from approximately 210 Mbbl to 90 MMbbl of combined-oil equivalent resources (fig. 21). The

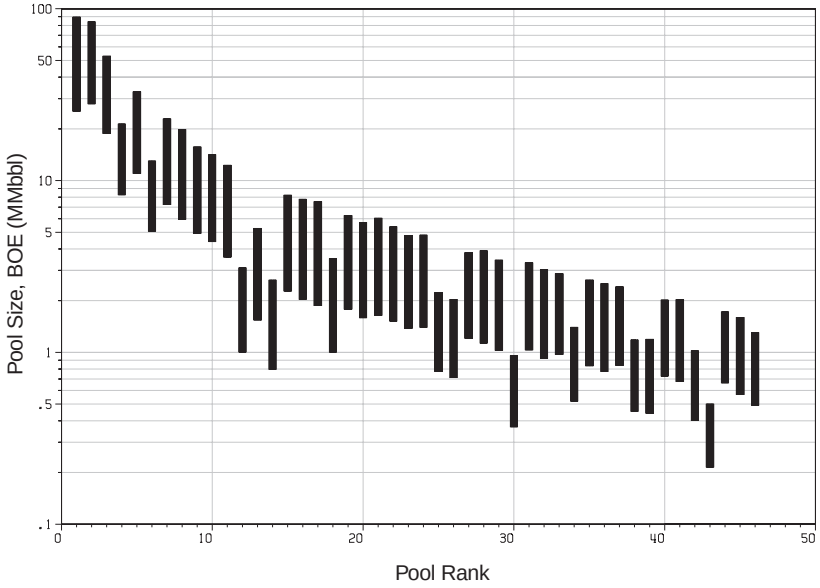


Figure 21. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the Growth Fault play, Washington-Oregon assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

majority of pools are expected to be oil pools (containing oil and associated gas); other pools may be gas pools (containing nonassociated gas and condensate) or mixed-commodity pools. The low, mean, and high estimates of resources in the play are listed in table 7.

NEOGENE FAN SANDSTONE PLAY

PLAY DEFINITION

The Neogene Fan Sandstone play of the Washington-Oregon assessment area is defined to include accumulations of oil and gas in Miocene and Pliocene sandstones deposited in deltaic and fan systems on the shelf and now incorporated in anticlinal, fault, and stratigraphic traps. It is a frontier play because there are indications of hydrocarbons within the play; however, no discoveries have been made. The play extends from Teawhit Head, Washington, to Newport, Oregon, with a separate subarea northwest of Coos Bay, Oregon (fig. 16). It encompasses areas offshore primary Neogene river systems, and covers about 5,000 square miles. It was defined primarily on the basis of reservoir rock stratigraphy.

The Neogene Fan Sandstone play is differentiated from the Neogene Shelf Sandstone play by the expectation of greater abundance of sand and larger grain size due to its more proximal location relative to sediment sourcing. Hydrocarbon accumulations may exist to about 12,000 feet below the seafloor.

Rocks that are probable equivalents to rocks of this play exist onshore and in State waters. These adjacent rocks are included in the Southwest Washington Miocene Sandstone and Astoria plays, which have been described and assessed by the USGS (Johnson and Tennyson, 1995).

PETROLEUM GEOLOGIC CHARACTERISTICS

Likely hydrocarbon source rocks include Eocene to Oligocene shales analogous to onshore strata in the Coos Bay area of south-coastal Oregon and Miocene and older melange, which underlies all other units throughout the area. Neogene shale interbeds are also considered possible source rocks by analogy with the Eel River basin. The melange is a less likely source for the eastern part of the areas off Oregon because a sequence of volcanic units separates it from the reservoir rocks of this play. Thicknesses of these rocks are unknown, but onshore rocks that may be equivalent are several thousand feet thick (Snavely and Wells, 1984; Snavely and others, 1980). North of Grays Harbor and along the western edge of the area offshore Coos Bay, Neogene rocks directly overlie melange. Geothermal gradients (Snavely, 1987; Palmer and Lingley, 1989) suggest that source rocks are likely to be mature for oil generation at burial depths greater than about 10,000 to 12,000 feet. Onshore data indicate that the Paleogene sedimentary rocks are gas prone (Brown and Ruth Laboratories, 1982; Niem and Niem, 1990); therefore, they are considered primarily a source of nonassociated gas regardless of burial depth. The melange is considered to be equivalent to rocks exposed onshore in the Olympic Mountains and south of the Eel River basin. Seeps at both locations and past production from melange near Grays Harbor and south of the Eel River basin suggest that the melange is primarily a source of high-gravity oil (Palmer and Lingley, 1989; Vander Leck, 1921; MacGinitie, 1943; California Division of Oil and Gas, 1960; 1982).

Potential reservoirs are expected to be of excellent to good quality. They consist of sandstones and siltstones deposited in shelf, slope, and submarine fan settings. The primary difference between this play and the Neogene Shelf Sandstone play is that within this play there is a greater likelihood of channel and thick fan deposits, so potential reservoir sandstones are likely to be thicker and coarser grained.

Potential traps include anticlinal folds, faults, and stratigraphic pinchouts. Offshore Washington and, to a lesser extent, offshore central Oregon, shale diapirs may provide both a source conduit and a trapping mechanism. The diapirs are sometimes associated with growth faults; but because they also occur alone, they are included among traps of the other Neogene plays. There is also a possibility of subthrust traps.

EXPLORATION

Exploratory wells at six sites have penetrated rocks of this play (fig. 16). Gas shows were reported in the Neogene section in two wells; gas in Paleogene rocks was reported in one of these. There is some indication of gas in Neogene rocks in a third well. Oil shows were reported in the Neogene section in one well and in the Paleogene section in two others.

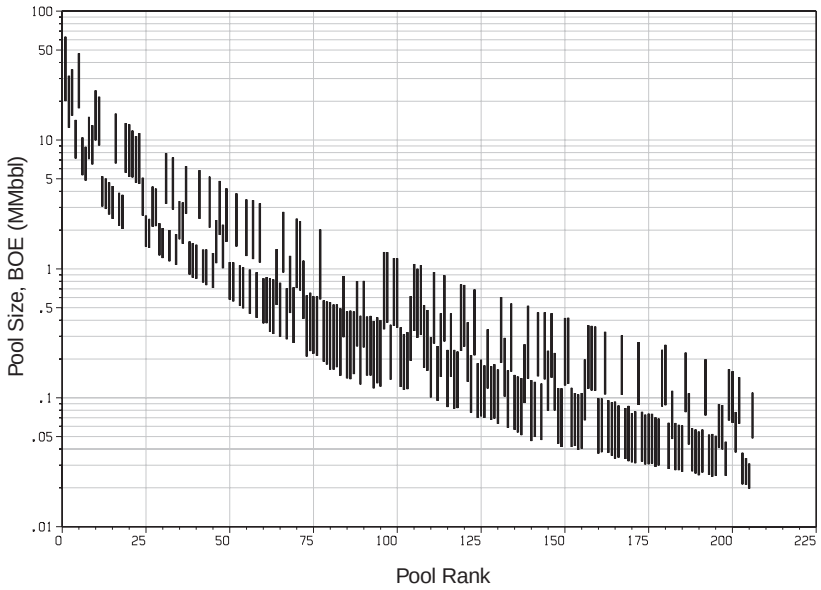


Figure 22. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the Neogene Fan Sandstone play, Washington-Oregon assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the play have been developed using the subjective assessment method. Select data used to develop the resource estimates are shown in appendix C.

The play was modeled as a mixed-commodity (oil with associated gas, and nonassociated gas with condensate) play on the basis of hydrocarbon shows and expected source rocks. Potential pools in the northern half of the northern subarea of the play are considered most likely to be oil pools because the melange is the primary source. In the southern half of the northern subarea and in the southern subarea, the pools are considered most likely to contain nonassociated gas sourced from the Paleogene section. Because of the low temperature gradient, oil generation is expected only where source rocks are present at burial depths greater than 10,000 feet. This is not a limiting factor for the melange source; however, it severely limits oil sourcing from the Paleogene section. Oil was modeled as a component of 45 percent of the expected pools; nonassociated gas was modeled as a component of 75 percent of the pools. Eel River basin prospect size and densities were used as analogs because structural style is similar; distributions of these variables were adjusted to account for the larger play area. Reservoir parameters were derived using data from analogous fields in California.

As a result of this assessment, the play is estimated to contain 98 MMbbl of oil (including oil and condensate) and 882 Bcf of gas (including associated and nonassociated gas) (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 206 pools with sizes ranging from approximately 20 Mbbl to 65 MMbbl of combined-oil equivalent resources (fig. 22). The majority of pools are expected to be gas pools (containing nonassociated gas and condensate); other pools may be oil pools (containing oil and associated gas) or mixed-commodity pools. The low, mean, and high estimates of resources in the play are listed in table 7.

NEOGENE SHELF SANDSTONE PLAY

PLAY DEFINITION

The Neogene Shelf Sandstone play of the Washington-Oregon assessment area is defined to include accumulations of oil and gas in Miocene and Pliocene sandstones deposited in deltaic and fan systems on the shelf and upper slope and now incorporated in anticlinal, fault, and stratigraphic traps. It is a conceptual play because no hydrocarbons have been identified within rocks of this play. The play extends from Cape Flattery, Washington, to south of Cape Blanco, Oregon; it extends over the shelf (exclusive of the area of the Neogene Fan Sandstone play) and encompasses about 13,000 square miles (fig. 16). It was defined primarily on the basis of reservoir rock stratigraphy.

The Neogene Shelf Sandstone play is differentiated from the Neogene Fan Sandstone play by the expectation of lesser thicknesses of sand layers and smaller grain size due to its more distal location relative to sediment sourcing. Hydrocarbon accumulations may occur from about 2,000 feet to about 12,000 feet below the seafloor.

PETROLEUM GEOLOGIC CHARACTERISTICS

Likely hydrocarbon source rocks include Eocene to Oligocene shales analogous to onshore strata in the Coos Bay area of south-coastal Oregon and Miocene and older melange, which underlies all other units throughout the area (fig. 17). Neogene shale interbeds are considered possible source rocks by analogy with the Eel River basin. The melange is a less likely source for most of the area south of Grays Harbor, Washington, because a sequence of volcanic units separates it from the reservoir rocks of this play. Thicknesses of these rocks are unknown, but onshore rocks that may be equivalent are several thousand feet thick (Snavely and Wells, 1984; Snavely and others, 1980). Offshore most of Washington and along the western margin of the play, Neogene rocks directly overlie melange. Geothermal gradients (Snavely, 1987; Palmer and Lingley, 1989) suggest that source rocks are likely to be mature for oil generation at burial depths greater than about 10,000 to 12,000 feet. Onshore data indicate that the Paleogene sedimentary rocks are gas prone (Brown and Ruth Laboratories, 1982; Niem and Niem, 1990); therefore, they are considered primarily a source of nonassociated gas regardless of burial depth. The melange is considered to be equivalent to rocks exposed onshore in the Olympic Mountains and south of the Eel River basin. Seeps at both locations and past production from melange near Grays Harbor and south of the Eel River basin suggest that the melange is primarily an oil source (Palmer and Lingley, 1989; Vander Leck, 1921; MacGinitie, 1943; California Division of Oil and Gas, 1960; 1982).

Potential reservoirs are expected to be of good to fair quality. They consist of siltstones and sandstones deposited in shelf, slope, and submarine fan settings. The primary difference from the Neogene Fan Sandstone play is that potential reservoir rock section in this play is likely to be much thinner and finer grained because of its relatively distal location.

Potential traps include anticlinal folds, faults, and stratigraphic pinchouts. Offshore Washington and, to a lesser extent, offshore central Oregon, shale diapirs may provide both a source conduit and a trapping mechanism. The diapirs are sometimes associated with growth faults, but because they also exist alone, they are included among traps of the other Neogene plays. There is also a possibility of subthrust traps.

EXPLORATION

Exploratory wells at four sites have penetrated rocks of this play (fig. 16). No hydrocarbon shows were reported in the Neogene section in these wells; however, gas shows were reported in the Paleogene section in three wells and an oil show was reported in one of those at about 11,000 feet measured depth.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the play have been developed using the subjective assessment method. Select data used to develop the resource estimates are shown in appendix C.

The play was modeled as a mixed-commodity (oil with associated gas, and nonassociated gas with condensate) play on the basis of hydrocarbon shows and expected source rocks. Potential pools in the western part of the play and in the part north of Grays Harbor are considered most likely to be high-gravity oil because the melange is the primary source. In the eastern part of the area south of Grays Harbor, nonassociated gas sourced from the Paleogene section is more likely to exist. Because of the low temperature gradient, oil generation is expected only where source rocks are present at burial depths

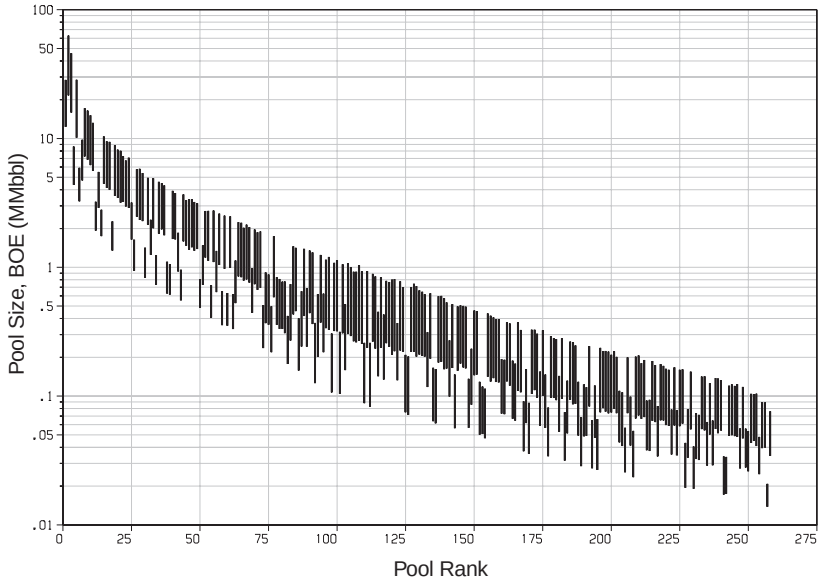


Figure 23. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the Neogene Shelf Sandstone play, Washington-Oregon assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

greater than 10,000 feet. This is not a limiting factor for the melange source; however, it severely limits oil sourcing from the Paleogene section. Oil was modeled as a component of 80 percent of the expected pools; nonassociated gas was modeled as a component of 40 percent of the pools. Eel River basin prospect sizes and densities were used as ana-logs, because structural style is similar; distributions of these variables were adjusted to account for the larger play area. Reservoir parameters were derived using data from analogous fields in California.

As a result of this assessment, the play is estimated to contain 138 MMbbl of oil (including oil and condensate) and 596 Bcf of gas (including associated and nonassociated gas) (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 258 pools with sizes ranging from approximately 15 Mbbl to 65 MMbbl of combined oil-equivalent resources (fig. 23). The majority of pools are expected to be oil pools (containing oil and associated gas); other pools may be gas pools (containing nonassociated gas and condensate) or mixed-commodity pools. The low, mean, and high estimates of resources in the play are listed in table 7.

PALEOGENE SANDSTONE PLAY

PLAY DEFINITION

The Paleogene Sandstone play of the Washington-Oregon assessment area is defined to include accumulations of oil and gas in Eocene and Oligocene sandstones. It is a frontier play because indications of hydrocarbons have been reported; however, no discoveries have been made. The play extends from Grays Harbor, Washington, to Coos Bay, Oregon; it encompasses the eastern part of the area, about 4,000 square miles (fig. 16). It was defined primarily on the basis of reservoir rock stratigraphy and includes Eocene and Oligocene sandstones deposited on the shelf and now incorporated in anticlinal, fault, and stratigraphic traps. These traps are expected to occur at about 2,000 to 20,000 feet burial depth.

Rocks that are possible equivalents to rocks of this play exist onshore and in State waters. These adjacent rocks are included in the Southwest Oregon Eocene Gas play, which has been described and assessed by the USGS (Johnson and Tennyson, 1995).

PETROLEUM GEOLOGIC CHARACTERISTICS

Source rocks include Eocene to Oligocene shales analogous to onshore strata in the Coos Bay area of south-coastal Oregon. Geothermal gradients (Snavely, 1987; Palmer and Lingley, 1989) suggest that source rocks are likely to be mature for oil generation at burial depths greater than 10,000 to 12,000 feet, although onshore data indicate that the rocks are primarily a source of nonassociated gas (Brown and Ruth Laboratories, 1982; Niem and Niem, 1990). The Paleogene sedimentary section attains depths of over 20,000 feet offshore central Oregon; however, diagenetic alteration and cementation are likely for arc-derived sediments at burial depths greater than about 15,000 feet (Galloway, 1979). On the western margin of the play area, there is the possibility for oil sourcing from the underlying melange.

Potential reservoirs are expected to be of poor to good quality. They consist of Eocene to Oligocene siltstones and sandstones deposited in shelf, slope, and submarine fan settings, and interbedded with the shales and mudstones.

Potential traps include anticlinal folds, faults, and stratigraphic pinchouts. There is also a possibility of subthrust traps. Trap seals may be provided by mudstones and shales; volcanic flows and sills, which are abundant within this section, may also provide seals.

EXPLORATION

Exploratory wells at eight sites have penetrated rocks presumed to be within this play (fig. 16); of these, five wells penetrated significant (greater than 3,000 feet) Paleogene section. Gas shows were reported in the Paleogene section in three wells; an oil show was reported in one well at about 11,000 feet measured depth.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the play have been developed using the subjective assessment method. Select data used to develop the resource estimates are shown in appendix C.

The play was modeled as a mixed-commodity (oil with associated gas, and nonassociated gas with condensate) play; however, it is a primarily nonassociated gas play on the basis of hydrocarbon shows and expected source rocks. Because of the low temperature gradient, oil generation is expected only where depth to the base of Paleogene strata is greater than 10,000 feet. Oil may also be present on the western margin of the play where sourcing from the underlying melange is more likely. In light of this possibility, oil (with associated gas) was modeled as a component of about 10 percent of the

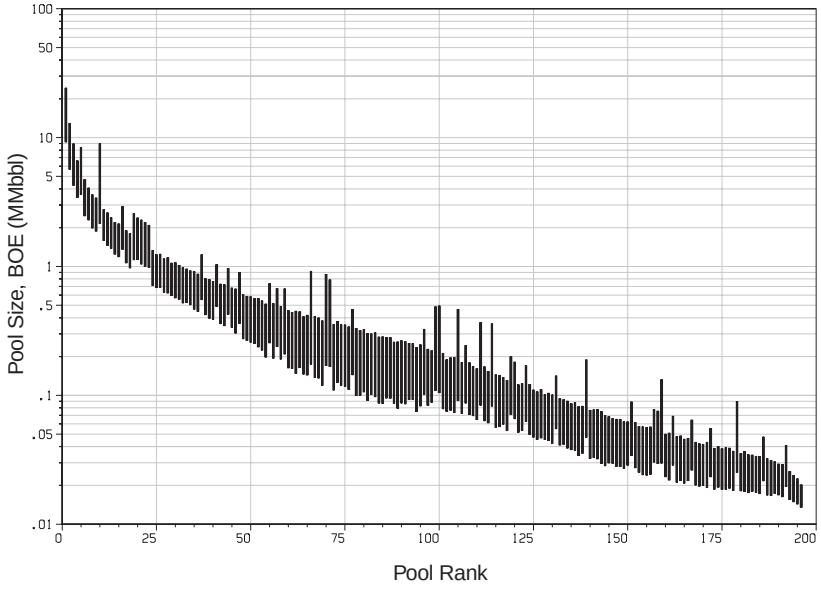


Figure 24. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the Paleogene Sandstone play, Washington-Oregon assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

expected pools. Eel River basin prospect sizes and densities were used as analogs, because structural style is similar; the distributions of these variables were adjusted to account for the larger play area. Reservoir parameters were derived using data from analogous fields in California.

As a result of this assessment, the play is estimated to contain 9 MMbbl of oil (including oil and condensate) and 372 Bcf of gas (including associated and nonassociated gas) (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 196 pools with sizes ranging from approximately 15 Mbbl to 25 MMbbl of combined oil-equivalent resources (fig. 24). The majority of pools are expected to be gas pools (containing nonassociated gas and condensate); other pools may be oil pools (containing oil and associated gas) or mixed-commodity pools. The low, mean, and high estimates of resources in the play are listed in table 7.

MELANGE PLAY

PLAY DEFINITION

The Melange play of the Washington-Oregon assessment area is defined to include accumulations of primarily oil and associated gas in discrete sandstone bodies within Eocene to Miocene rocks, which are subjacent to the mappable sedimentary section. Its extent is areawide, from Cape Flattery, Washington, to south of Cape Blanco, Oregon; it encompasses about 18,000 square miles (fig. 16). The upper part of this section, to the depth penetrated by exploratory wells, is considered to be primarily olistostrome and turbidite deposition on or near the continental slope. Below this is expected a tectonic melange resulting from shearing within the subduction complex. The boundary between these can not be determined from the seismic-reflection data. Hydrocarbons may exist in fractures within the tectonically sheared shale matrix as well as in sandstone lenses, which were the basis for trap modeling. In either case, individual hydrocarbon accumulations are expected to be small because of the sheared and discontinuous nature of rock units observed in melanges of this type.

Rocks that are lithologically and genetically equivalent to rocks of this play are exposed onshore in the western Olympic Mountains and exist elsewhere onshore and in State waters in the subsurface. These adjacent rocks are included in the Western Washington Melange play, which has been described and assessed by the USGS (Johnson and Tennyson, 1995).

PETROLEUM GEOLOGIC CHARACTERISTICS

The melange is expected to be both source and reservoir for this play. Seeps in the onshore area on the Olympic Peninsula and south of Eel River basin suggest it is a source at least locally. Reservoirs are expected to be relatively small, discontinuous sandstone lenses incorporated into a matrix of shale and mudstone from which they are sourced. The small pool sizes indicated by the discovery history are probably typical and are consistent with that model. There is no way to identify or predict the locations of larger sand bodies given the lack of seismic signature, and there is no expectation for future advances in technology to increase this likelihood.

EXPLORATION

Three offshore exploratory wells penetrated rocks of this play. Oil shows were encountered within the melange section in two of the three wells, and gas shows were encountered in one of those two. Petroliferous mudstones of Eocene to Miocene turbidite and melange sequences on the Olympic Peninsula, Washington (Palmer and Lingley, 1989), and Tertiary rocks of the Coastal Belt of the Franciscan Complex south of the Eel River basin are considered to be equivalent to rocks within this play. Past production of oil occurred in the Ocean City field near Grays Harbor, Washington (Palmer and Lingley, 1989), and in the Petrolia area south of the Eel River basin (Stalder, 1914; Harmon, 1914; Vander Leck, 1921; MacGinitie, 1943; California Division of Oil and Gas, 1960; 1982). The only field designated in the Petrolia area (Petrolia field) was only a few hundred barrels, and the Ocean City field produced about 12 Mbbl.

RESOURCE ASSESSMENT

This play was not quantitatively assessed, although it is considered to be an important source of oil for the other plays in the area. It is a frontier play because there is evidence of hydrocarbon generation; however, the likelihood that accumulations of producible size exist is considered too low for this to be considered a viable play.

EEL RIVER BASIN

by Kenneth A. Piper

LOCATION

The Eel River basin is the southern subarea of the Pacific Northwest province (fig. 13). It extends from "Retirement ridge" (an informally named structural high) offshore of Gold Beach, Oregon, to Cape Mendocino, California. The basin is about 125 miles long and 30 miles wide and extends onshore about 25 miles in the vicinity of Eureka, California (fig. 25).

The Eel River Basin assessment area comprises only the Federal offshore portion of the basin (i.e., seaward of the 3-mile line) and encompasses about 3,200 square miles. Water depth in the assessment area ranges from about 200 feet at the 3-mile line to about 4,000 feet locally along the western limit of the basin.

GEOLOGIC SETTING

Tertiary sedimentary units throughout the Eel River basin are most likely underlain by a subduction melange (fig. 26). In the eastern offshore part of the basin, these rocks are apparently continuous

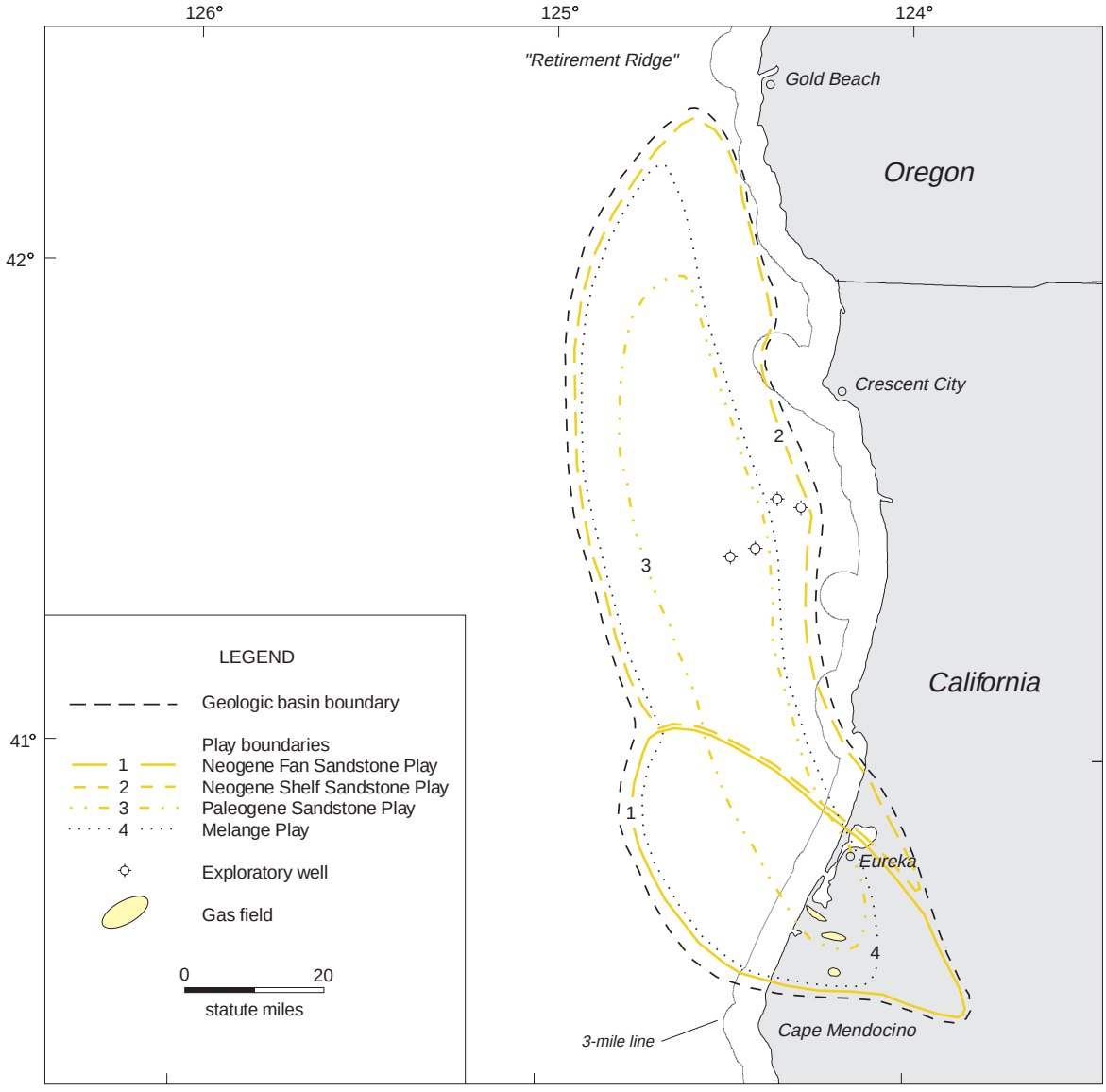


Figure 25. *Map of the Eel River Basin assessment area showing petroleum geologic plays, wells, and fields.*

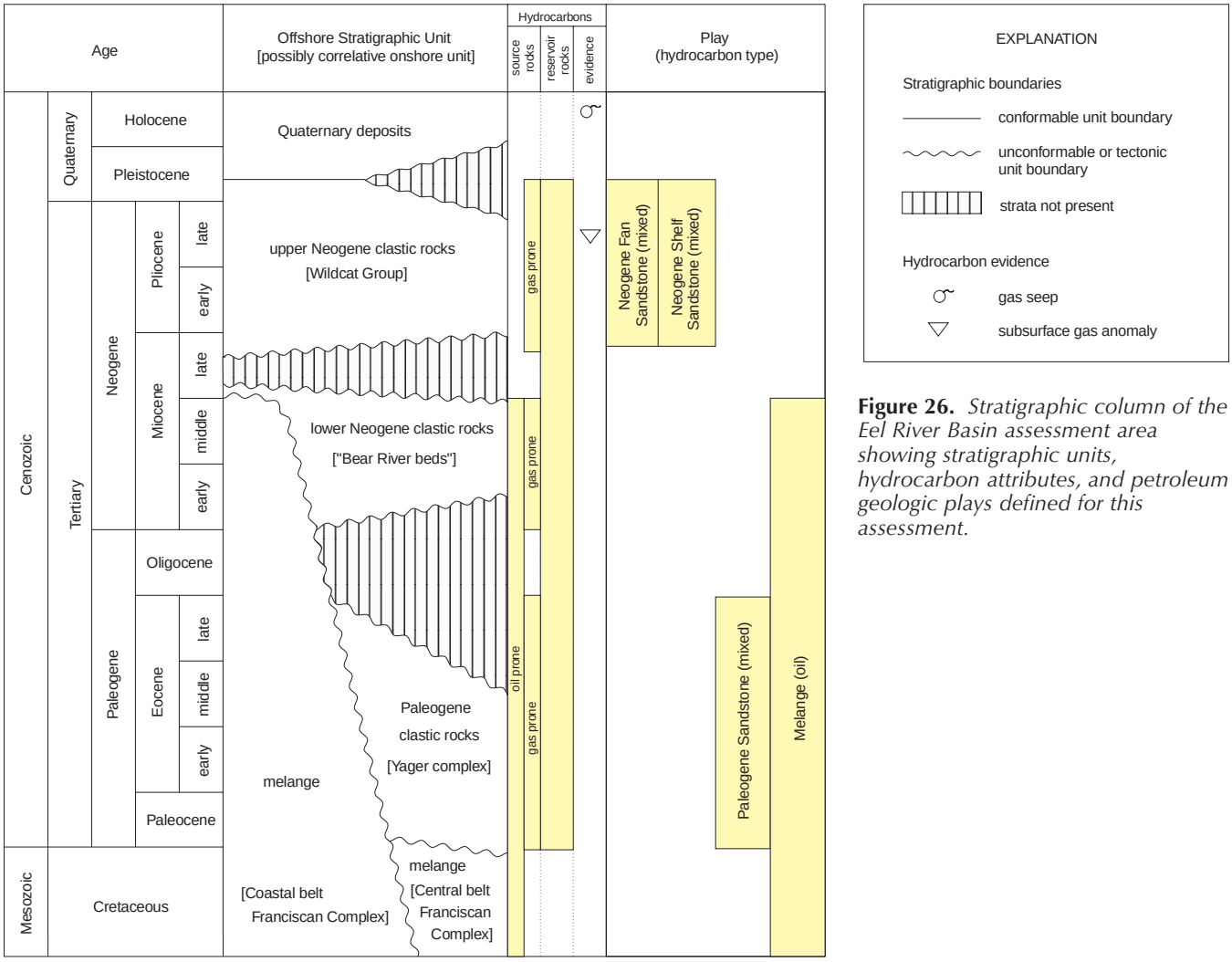


Figure 26. *Stratigraphic column of the Eel River Basin assessment area showing stratigraphic units, hydrocarbon attributes, and petroleum geologic plays defined for this assessment.*

with onshore rocks of the Jurassic to Cretaceous Eastern and Central belts of the Franciscan Complex (equivalent to Dothan Formation and related rocks in Oregon (Jayko and Blake, 1987)) as described by Clarke (1992). The melange under the western part of the basin is probably continuous with the mostly Tertiary Coastal belt of the Franciscan Complex. The latter unit, along with the overlying Yager complex, is thrust under the older Central belt rocks along an east-dipping blind reverse fault, which is the probable offshore extension of the Freshwater fault of Ogle (1953). Onshore exposures of this fault have also been called the "Coastal Belt thrust" by Jones and others (1978) and Aalto and others (1995), and the "Eel River fault" by Bachman and others (1984). As described by Underwood (1985), the Yager "structural complex" (a member of the Coastal belt Franciscan as defined by the USGS) includes turbidite sequences of shelf to slope depositional environments and lacks the pervasive stratal disruption and "exotic" blocks that are found in subduction complexes. It probably represents trench-slope and slope-basin sediments deposited atop the accreted units of the Coastal belt Franciscan (Bachman and others, 1984). If so, it may be genetically equivalent to the upper, depositional part of the melange in the Washington-Oregon assessment area. The Yager complex is overlain by Neogene and Quaternary clastic strata, which attain a thickness of over 12,000 feet in the offshore part of the basin. Along the western margin of the basin, Neogene strata may directly overlie the Coastal belt.

Fault and fold trends range from predominantly west-northwest onshore and in the southern offshore part of the basin to north-northwest in the northern part of the basin. Shale diapirs are common, especially in the southern part of the basin, and are often associated with faulting.

The spatial relationship between the older Eastern and Central belts of the Franciscan Complex and the

younger Coastal belt suggests that Mesozoic subduction occurred east of the present trench and that in the early Tertiary the locus of subduction migrated westward. This pattern is similar to the middle to late Tertiary migration of subduction described for the Washington-Oregon assessment area. The basin may at present be undergoing a change from a forearc to a strike-slip basin (Bachman and Crouch, 1987; Crouch and Bachman, 1987).

EXPLORATION AND DISCOVERY STATUS

Four exploratory wells were drilled in the central part of offshore Eel River basin in the 1960's. All were drilled on a structural high of Franciscan Complex rocks; only two wells penetrated significant Tertiary section before bottoming in the Franciscan rocks. The only indication of hydrocarbons encountered in the offshore wells was veins of gilsonite (an asphalt) in a core from the bottom of well OCS-P 0019 #1 (Zieglar and Cassell, 1978). However, gas has been recovered from a sample of unconsolidated sediment (Field and others, 1980), and abundant gas seeps have been mapped in the southern part of the offshore basin (Fairfield Industries, Inc., 1980; Kvenvolden and others, 1980; Kvenvolden and Field, 1981; Field and Kvenvolden, 1987).

Nonassociated gas has been produced from Neogene strata in three onshore gas fields. Tompkins Hill gas field was discovered in 1937 and production is ongoing. Most production is from fan-channel sands within the Rio Dell Formation (Crouch, Bachman, and Associates, Inc., 1988a). Ultimate production is expected to be about 120 Bcf of gas (Parker, 1987; California Division of Oil, Gas, and Geothermal Resources, 1995). Table Bluff field was discovered in 1960 and may contain as much as 8.5 Bcf of gas (Stanley, 1995a); however, the field was abandoned in 1968 after producing only 109 MMcf of gas (California Division of Oil, Gas, and Geothermal Resources, 1995). Grizzly Bluff field was discovered in 1964 (California Division of Oil and Gas, 1969) and may contain 2 to 3 Bcf of gas (Stanley, 1995a); however, no commercial production was ever established.

Onshore, south of the Eel River basin, the Petrolia field produced about 350 barrels of high-gravity (46 °API) oil from 1953 to 1954 (California Division of Oil and Gas, 1960; 1982). Abundant oil seeps exist, and minor amounts of high-gravity oil have been produced since the 1860's from wells drilled elsewhere in Coastal belt Franciscan and associated Tertiary rocks south of Eel River basin. In the same area, a well produced small amounts of gas for more than 40 years in the early part of the century from Yager or associated Neogene strata (Stalder, 1914; Harmon, 1914; Vander Leck, 1921; MacGinitie, 1943; Ogle, 1953).

The offshore geology has been extrapolated from the offshore well data and onshore geologic information and interpreted using a moderate to dense grid of seismic-reflection data. Prospect mapping in preparation for Lease Sale 53 (later limited to Santa Maria basin) and Lease Sale 91 (canceled) is the basis for parameters relating to prospects in plays of this basin and for analogous plays in the Washington-Oregon assessment area.

PLAYS

For this assessment, four petroleum geologic plays were defined, based on reservoir rock stratigraphy and source characteristics (figs. 25 and 26). Two Neogene Sandstone plays, a Paleogene Sandstone play, and a Melange play were so defined. The plays are described following this assessment area summary. Rocks in the onshore portions of the Neogene Sandstone plays are equivalent to rocks that are included in the Eel River Gas play of the Northern Coastal province, which was assessed by the USGS (Stanley, 1995a). Rocks in the onshore and State offshore portions of the Paleogene Sandstone and Melange plays are equivalent to rocks that are a part of the Franciscan Oil and Gas play of the Northern Coastal province, which was described but not quantitatively assessed by the USGS (Stanley, 1995a).

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Play-specific estimates of undiscovered conventionally recoverable resources have been developed using the subjective assessment method, and these estimates have been statistically aggregated to estimate the total volume of resources in the assessment area. Select data used to develop the resource estimates are shown in appendix C.

As a result of this assessment, the total volume of undiscovered conventionally recoverable resources in the Eel River Basin assessment area is estimated to be 55 MMbbl of oil (including oil and condensate) and 1.61 Tcf of gas (including associated and nonassociated gas) (mean estimates). This volume may exist in 156 fields with sizes ranging from approximately 10 Mbbl to 50 MMbbl of combined oil-equivalent resources (fig. 27). The low, mean, and high estimates of resources in the area are listed in table 9 and illustrated in figure 28.

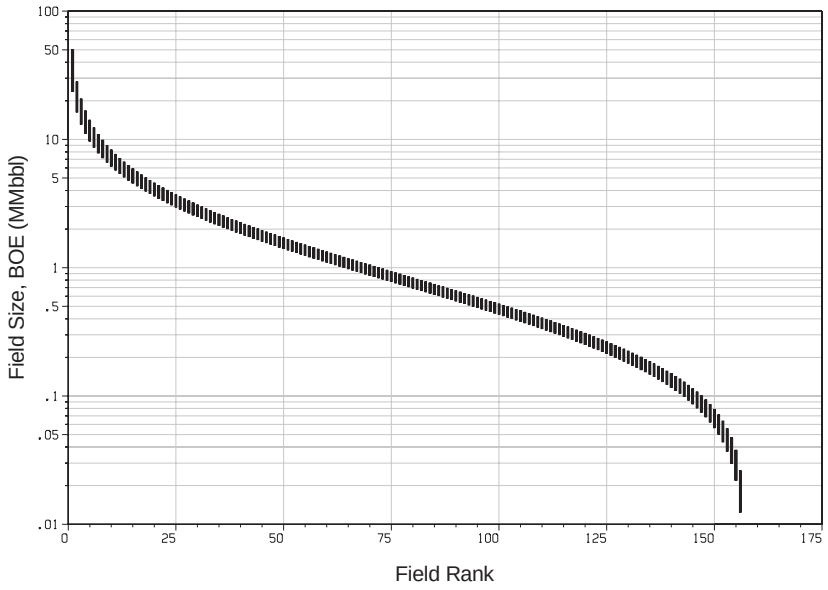


Figure 27. *Field-size rank plot of estimated undiscovered conventionally recoverable resources of the Eel River Basin assessment area. Sizes of undiscovered fields are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

Table 9. *Estimates of undiscovered conventionally recoverable oil and gas resources in the Eel River Basin assessment area as of January 1, 1995, by play. All estimates are risked values. The low, mean, and high estimates correspond to the 95th-percentile, mean, and 5th-percentile values of a probability distribution, respectively. Percentile values are not additive; some total mean values may not equal the sum of the component values due to independent rounding.*

Play	Oil (MMbbl)			Gas (Bcf)			BOE (MMbbl)		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Neogene Fan Sandstone	9	17	29	429	639	1,000	90	131	198
Neogene Shelf Sandstone	0	34	52	0	943	1,266	0	202	269
Paleogene Sandstone	0	4	12	0	31	110	0	9	31
Melange	not assessed								
Total Assessment Area	*33*	*55*	*84*	*1,061*	*1,612*	*2,316*	*227*	*342*	*488*

Figure 28. *Cumulative probability plot of estimated undiscovered conventionally recoverable resources of the Eel River Basin assessment area.*

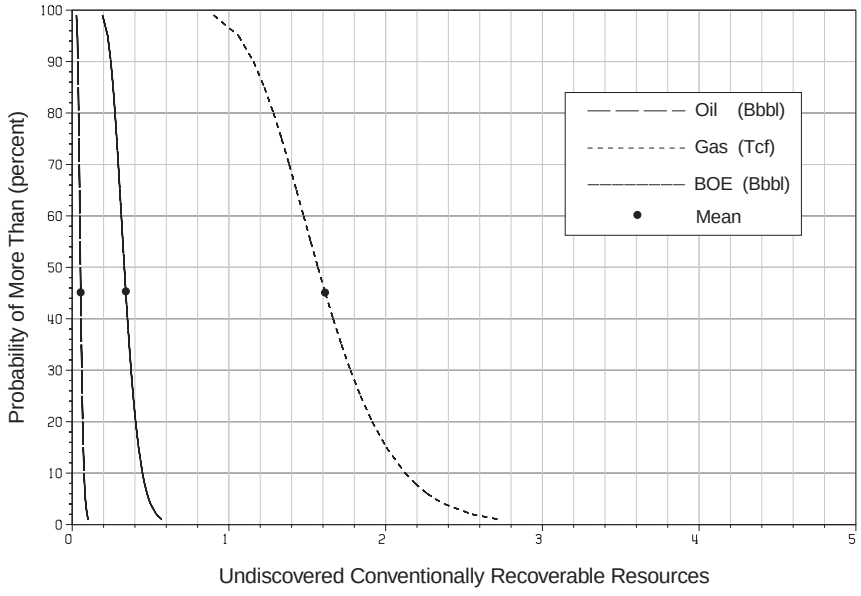


Table 10. *Estimates of undiscovered economically recoverable oil and gas resources in the Eel River Basin assessment area as of January 1, 1995, by economic scenario. All estimates are risked mean values. The $18-per-barrel scenario is based on prices of $18 per bbl of oil and $2.11 per Mcf of gas; the $25-per-barrel scenario is based on prices of $25 per bbl of oil and $2.94 per Mcf of gas; the $50-per-barrel scenario is based on prices of $50 per barrel of oil and $5.87 per Mcf of gas.*

Economic Scenario	Oil (MMbbl)	Gas (Bcf)	BOE (MMbbl)
$18 per barrel	9	280	59
$25 per barrel	13	419	88
$50 per barrel	25	766	162

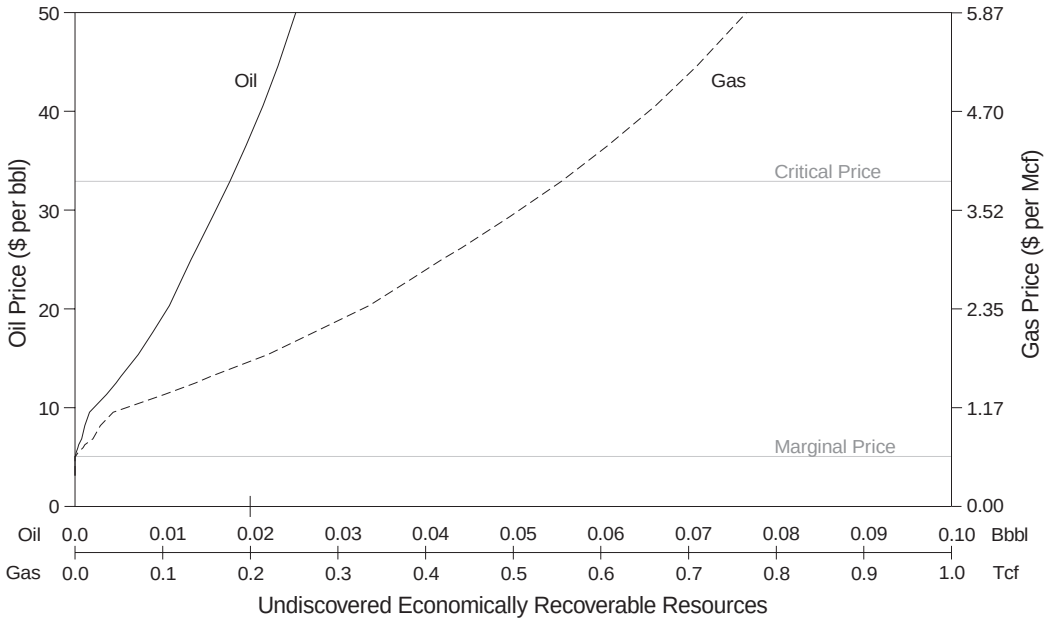


Figure 29. *Price-supply plot of estimated undiscovered economically recoverable resources of the Eel River Basin assessment area.*

Undiscovered Economically Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the assessment area that may be economically recoverable under various economic scenarios have been developed using the economic assessment method. Select data used to develop the resource estimates are shown in appendix D.

As a result of this assessment, 9 MMbbl of oil (including oil and condensate) and 280 Bcf of gas (including associated and nonassociated gas) are estimated to be economically recoverable from the Eel River Basin assessment area under economic conditions existing as of this assessment (i.e., the $18-per-barrel economic scenario) (table 10). Larger volumes of resources are expected to be economically recoverable under increasingly favorable economic conditions (fig. 29).

Total Resource Endowment

No accumulations of resources have been discovered in the assessment area. Therefore, the aforementioned estimates of undiscovered conventionally recoverable resources compose the estimated total aforeresource endowment of the area.

Acknowledgments

Rick Stanley (U.S. Geological Survey) and Jim Crouch (J.K. Crouch and Associates, Inc.) provided information, insight, and suggestions that improved the quality of this assessment of the Eel River basin. Previous geophysical interpretations by Jim Cummings and Peter Simon of MMS provided the basis for the present study.

Additional References

McLean and Wiley, 1987
Webster and others, 1986
Webster and Yenne, 1987

NEOGENE FAN SANDSTONE PLAY

PLAY DEFINITION

The Neogene Fan Sandstone play of the Eel River Basin assessment area is defined to include accumulations of oil and gas in Miocene to Pleistocene sandstones deposited in deltaic and fan systems of the ancestral and present Eel River and now incorporated in anticlinal, fault, and stratigraphic traps. It is an established play because it extends onshore where there is ongoing gas production. The play extends northwesterly offshore the Eel River and encompasses the southern one-fifth of the offshore Eel River basin (fig. 25). The Federal offshore part of the play (an area of about 600 square miles) has been assessed. The play is defined primarily on the basis of reservoir rock stratigraphy.

The Neogene Fan Sandstone play is differentiated from the Neogene Shelf Sandstone play by the expectation of a greater abundance of channel sandstones and larger grain size due to its more proximal location relative to sediment sourcing. Hydrocarbon accumulations are expected to occur to about 10,000 feet below the seafloor.

Some of the rocks of this play extend onshore and into State waters. These are included as a part of the Eel River Gas play of the Northern Coastal province, which was assessed by the USGS (Stanley, 1995a).

PETROLEUM GEOLOGIC CHARACTERISTICS

Potential source rocks include the Cretaceous(?) to Miocene Coastal belt of the Franciscan Complex and Tertiary deltaic and forearc basin strata (fig. 26). Kerogen type of onshore samples suggests the Coastal belt is primarily gas prone (Crouch, Bachman, and Associates, Inc., 1987); however, production from this unit south of the Eel River basin is primarily high-gravity oil (California Division of Oil and Gas, 1960; 1982). Kerogen type and onshore production indicate that the Tertiary strata may be a source of primarily non-associated gas. Thermal gradients (Underwood, 1985; Crouch, Bachman, and Associates, Inc., 1988a) suggest that source rocks are likely to be mature for oil generation at burial depths greater than 7,000 to 12,000 feet; however, the play is considered to be primarily a gas play on the basis of onshore production experience and abundant offshore gas seeps.

Potential reservoirs are expected to be of excellent to good quality. They consist of channel and fan sandstones and siltstones in the Rio Dell, Eel River, and Pullen Formations of the Miocene to Pleistocene Wildcat Group (MacGinitie, 1943; Ogle, 1953; Crouch, Bachman, and Associates, Inc., 1988a). Offshore, this section is up to about 10,000 feet thick, based on geophysical interpretation.

Potential traps include anticlinal folds, faults, and stratigraphic pinchouts. There is also a possibility of subthrust traps. The largest identified prospect offshore is about the size of the onshore Tompkins Hill gas field (1,400 acres).

EXPLORATION

No exploratory wells have been drilled in the Federal offshore part of this play.

Gas measurements in the water column indicate hydrocarbons are present, although some may be of biogenic origin. Onshore, gas has been discovered and produced from three fields: Tompkins Hill (active with estimated ultimate production of 120 Bcf of gas), Table Bluff (abandoned), and Grizzly Bluff (abandoned). Most of the gas has been produced from the Rio Dell Formation; however, gas was tested in the Eel River and Pullen Formations in the Table Bluff field.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the Federal offshore portion of the play have been developed using the subjective assessment method. Select data used to develop the resource estimates are shown in appendix C.

The play was modeled as primarily gas on the basis of the onshore gas production and offshore gas seeps. Due to the minor oil production from the Coastal belt Franciscan and its position as a possible source rock, oil was modeled as a component of about 20 percent of the expected pools. Play-specific prospect areas and the number of prospects were estimated based on detailed seismic mapping that used a dense (less than 1-mile spacing) grid of data. Reservoir parameters were derived using data from the onshore Tompkins Hill and Table Bluff gas fields and from analogous fields elsewhere in California.

As a result of this assessment, the Federal offshore portion of the play is estimated to contain 17 MMbbl of oil (including oil and condensate) and 639 Bcf of gas (including associated and nonassociated gas) (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 80 pools with sizes ranging from approximately 30 Mbbl to 40 MMbbl of combined

oil-equivalent resources (fig. 30). The majority of pools are expected to be gas pools (containing nonassociated gas and condensate); other pools may be oil pools (containing oil and associated gas) or mixed-commodity pools. The low, mean, and high estimates of resources in the play are listed in table 9.

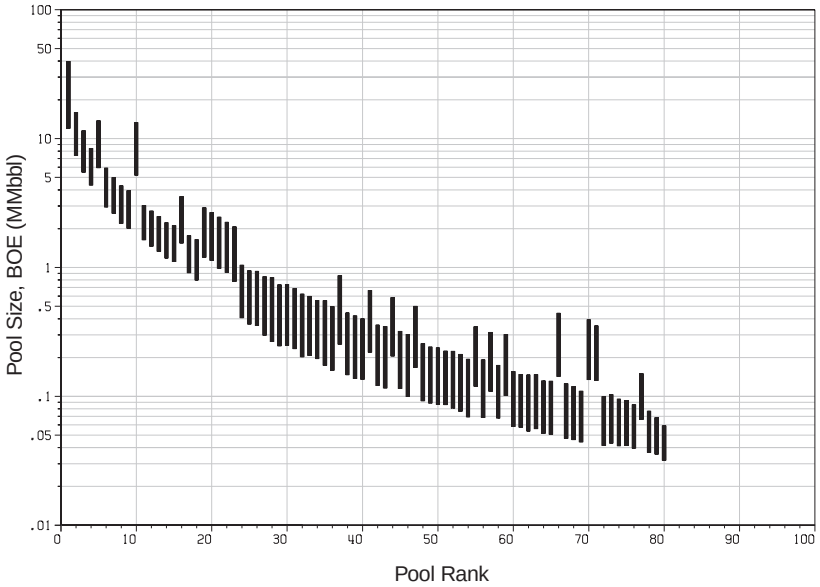


Figure 30. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the Neogene Fan Sandstone play, Eel River Basin assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

NEOGENE SHELF SANDSTONE PLAY

PLAY DEFINITION

The Neogene Shelf Sandstone play of the Eel River Basin assessment area is defined to include accumulations of oil and gas in Neogene sandstones outside the primary area of influence of the ancestral and present Eel River deltaic system. It is a frontier play because no discoveries have been made; however, seismic-reflection profiles and gas seeps strongly suggest the presence of gas accumulations. The play extends northward from the Neogene Fan Sandstone play to encompass the remaining four-fifths of the Eel River Basin assessment area, an area of about 2,600 square miles (fig. 25). It was defined primarily on the basis of reservoir rock stratigraphy. It includes Miocene to Pleistocene sandstones deposited on the shelf and now incorporated in anticlinal, fault, and stratigraphic traps.

The Neogene Shelf Sandstone play is differentiated from the Neogene Fan Sandstone play by the expectation of lesser thicknesses of sand layers and smaller grain size due to its more distal location relative to sediment sourcing. These traps are expected to exist to about 8,000 feet below the seafloor.

Some of the rocks of this play extend onshore and into State waters. These are included as a part of the Eel River Gas play of the Northern Coastal province, which was assessed by the USGS (Stanley, 1995a).

PETROLEUM GEOLOGIC CHARACTERISTICS

Potential source rocks include the Cretaceous(?) to Miocene Coastal belt Franciscan and Tertiary deltaic and forearc basin strata (fig. 26). Kerogen type of onshore samples suggests the Coastal belt is primarily gas prone (Crouch, Bachman, and Associates, Inc., 1987); however, production from this unit south of the Eel River basin is primarily high-gravity oil (California Division of Oil and Gas, 1960; 1982). Kerogen type and onshore production indicate that the Tertiary strata may be a source of primarily nonassociated gas. Thermal gradients (Underwood, 1985; Crouch, Bachman, and Associates, Inc., 1988a) suggest that source rocks are likely to be mature for oil generation at burial depths greater than 7,000 to 12,000 feet; however, the play is considered to be primarily a gas play on the basis of onshore gas production and abundant offshore seeps.

Potential reservoirs are expected to be of good to fair quality. They consist of sandstones and siltstones in rocks correlative with the Rio Dell, Eel River, and Pullen Formations of the Miocene to Pleistocene Wildcat Group. Geophysical interpretation indicates the Neogene section is up to about 8,000 feet thick, based on geophysical interpretation.

Potential traps include anticlinal folds, faults, and stratigraphic pinchouts. There is also a possibility of subthrust traps. Prospect sizes were estimated to be about the same as for the Neogene Fan Sandstone play.

EXPLORATION

In the 1960's, four offshore exploratory wells were drilled in the eastern central part of the play. Only two wells penetrated significant Tertiary section. No hydrocarbon shows were reported within Tertiary section in any of the wells. Gas measurements in the water column in the southern and central parts of the basin indicate hydrocarbons are present, although some may be of biogenic origin.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the Federal offshore portion of the play have been developed using the subjective assessment method. Select data used to develop the resource estimates are shown in appendix C.

The play was modeled as primarily gas on the basis of the onshore gas production and offshore gas seeps. Due to minor oil production from the Coastal belt Franciscan and its position as a possible source rock, oil was modeled as a component of about 20 percent of expected pools. Based on a moderate grid of seismic data, prospect sizes and densities were estimated to be about the same as for the Neogene Fan Sandstone play. This analogous play was mapped using a denser grid of seismic data; its prospect size and density distributions were adjusted to account for the larger area of the Neogene Shelf Sandstone play. Reservoir parameters were derived using data from the onshore Tompkins Hill and Table Bluff gas fields and from analogous fields elsewhere in California.

As a result of this assessment, the Federal offshore portion of the play is estimated to contain 34 MMbbl of oil (including oil and condensate) and 943 Bcf of gas (including associated and nonassociated gas) (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 230 pools with sizes ranging from approximately 20 Mbbl to 35 MMbbl of combined oil-equivalent resources (fig. 31). The majority of pools are expected to be gas pools (containing nonassociated gas and condensate); other pools may be oil pools (containing oil and associated gas) or mixed-commodity pools. The low, mean, and high estimates of resources in the play are listed in table 9.

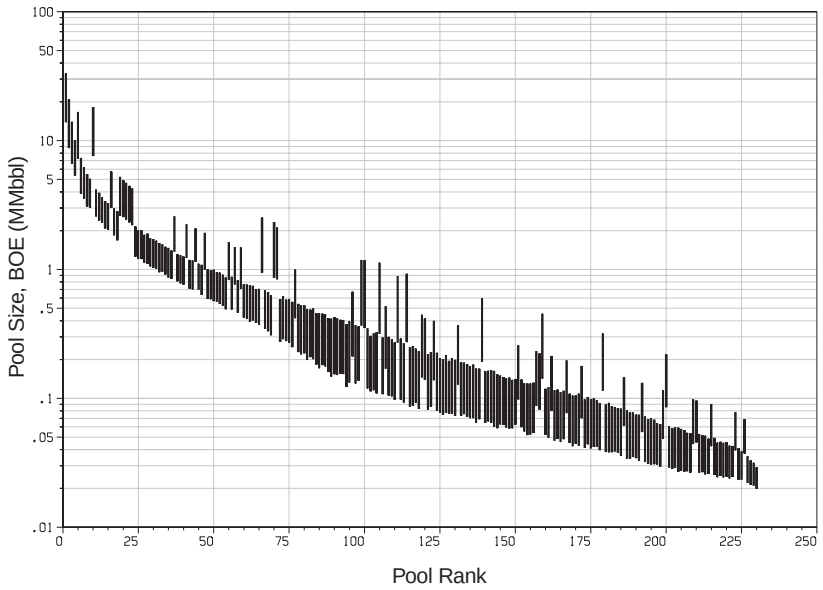


Figure 31. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the Neogene Shelf Sandstone play, Eel River Basin assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

PALEOGENE SANDSTONE PLAY

PLAY DEFINITION

The Paleogene Sandstone play of the Eel River Basin assessment area is defined to include accumulations of oil and gas in Paleogene sandstones. It is a conceptual play because hydrocarbons have not been detected within the play. The play extends northward from Humboldt Bay encompassing the central part of the Eel River basin and an area of about 900 square miles (fig. 25). It was defined primarily on the basis of reservoir rock stratigraphy and includes Paleocene to Eocene sandstones resulting from olistostrome and turbidite deposition on the continental slope and now incorporated in anticlinal, fault, and stratigraphic traps. Rocks of this play may be correlative with the upper part of the Melange play of the Washington-Oregon assessment area. Traps are expected to occur at burial depths of about 3,000 to 8,000 feet.

Some of the rocks of this play extend onshore and into State waters. These are included as a part of the Franciscan Oil and Gas play, which was defined but not quantitatively assessed by the USGS (Stanley, 1995a).

PETROLEUM GEOLOGIC CHARACTERISTICS

Source rocks include the Cretaceous(?) to Miocene Coastal belt Franciscan Complex, including shales of the Paleogene Yager member of the Coastal belt (fig. 26). Kerogen type of onshore samples suggests the Coastal belt is primarily gas prone (Underwood, 1987; Crouch, Bachman, and Associates, Inc., 1987; 1988a); however, production from Coastal belt rocks south of the Eel River basin is primarily high-gravity oil (Vander Leck, 1921; MacGinitie, 1943, California Division of Oil and Gas, 1960; 1982). Thermal gradients (Underwood, 1985; Crouch, Bachman, and Associates, Inc., 1988a) indicate that source rocks are likely to be mature for oil generation at burial depths greater than 7,000 to 12,000 feet; the play is considered to be a mixed-commodity (oil with associated gas, and nonassociated gas with condensate) play on the basis of likely source rocks.

Potential reservoirs are expected to be of fair to poor quality. They consist of sandstones and siltstones of the Yager complex resulting from turbidite and olistostrome deposition in slope and submarine fan settings. At many onshore localities, sandstones

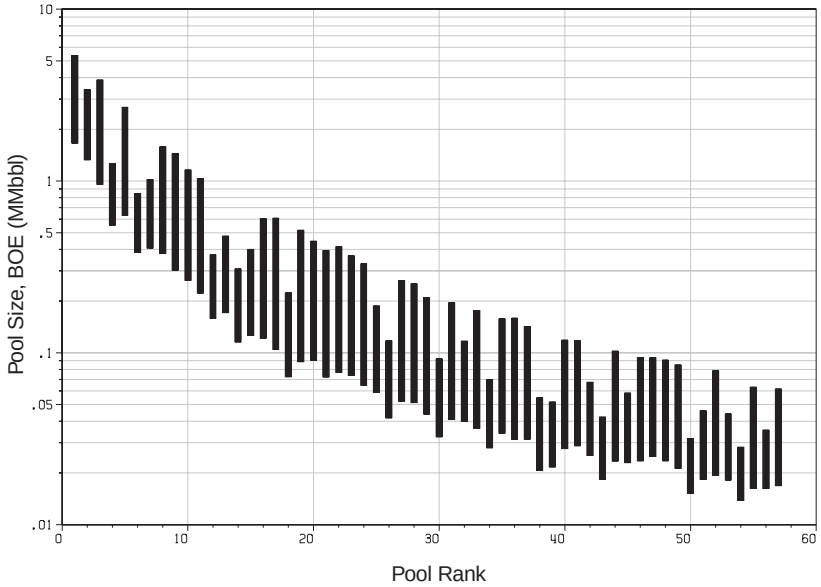


Figure 32. *Pool-size rank plot of estimated undiscovered conventionally recoverable resources of the Paleogene Sandstone play, Eel River Basin assessment area. Sizes of undiscovered pools are shown by bars; the top and bottom of a bar represent the 25th- and 75th-percentile values of a probability distribution, respectively.*

of the Yager are well cemented with laumontite filling pore spaces (Crouch, Bachman, and Associates, Inc., 1988a).

Potential traps include anticlinal folds, faults, and stratigraphic pinchouts. There is also a possibility of subthrust traps.

EXPLORATION

In the 1960's, two exploratory wells (OCS-P 0014 #1 and OCS-P 0019 #1) were drilled in the eastern central part of the play and penetrated Eocene strata. The only indication of hydrocarbons was the presence of gilsonite (asphalt) veins in a core from the bottom of OCS-P 0019 #1 (Zieglar and Cassell, 1978). Onshore, one gas well south of the Eel River basin produced small quantities for more than 40 years in the early part of the century from Yager or associated Neogene strata (Vander Leck, 1921; MacGinitie, 1943). Numerous oil seeps and minor oil production (from the Petrolia field) occurred in Coastal belt rocks south of the Eel River basin.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of undiscovered conventionally recoverable resources in the Federal offshore portion of the play have been developed using the subjective assessment method. Select data used to develop the resource estimates are shown in appendix C.

The play was modeled as a mixed-commodity (oil with associated gas, and nonassociated gas with condensate) play on the basis of the expected source rocks. Due to minor oil production from the Coastal belt Franciscan and its position as a possible source rock, the resource potential of this play was weighted toward oil. Gas was modeled as a component of about half of the expected pools. Prospect sizes and densities were estimated to be about the same as for the Neogene Fan Sandstone play. This analogous play was mapped with a denser grid of seismic data; its prospect size and density distributions were adjusted to account for the larger play area of the Paleogene Sandstone play. Reservoir parameters were derived using data from analogous fields elsewhere in California.

As a result of this assessment, the Federal offshore portion of the play is estimated to contain 4 MMbbl of oil (including oil and condensate) and 31 Bcf of gas (including associated and nonassociated gas) (mean estimates). This volume of undiscovered conventionally recoverable resources may exist in as many as 57 pools with sizes ranging from approximately 15 Mbbl to 5 MMbbl of combined oil-equivalent resources (fig. 32). The majority of pools are expected to be oil pools (containing oil and associated gas); other pools may be gas pools (containing nonassociated gas and condensate) or mixed-commodity pools. The low, mean, and high estimates of resources in the play are listed in table 9.

MELANGE PLAY

PLAY DEFINITION

The Melange play of the Eel River Basin assessment area is defined to include accumulations of oil and associated gas in discrete sandstone bodies within Tertiary rocks of the Coastal belt of the Franciscan Complex. These rocks are subjacent to the mappable sedimentary section over most of the play area; along the eastern margin they are thrust under rocks of the Central belt of the Franciscan Complex. The play's extent is basin-wide (west of the contact with the Central belt), from Gold Beach, Oregon, to Cape Mendocino, California; it encompasses about 3,200 square miles (fig. 25). The Yager complex (Paleogene Sandstone play) may be the result of turbidite and olistostrome deposition on or near the continental slope and, as such, would be correlative with the upper part of the Melange play in the Washington-Oregon assessment area. Below the Yager, rocks of the Melange play are a tectonic melange resulting from shearing within the subduction complex. The boundary between the Yager and underlying tectonic melange cannot be clearly established from the seismic-reflection data. Hydrocarbons may exist in fractures within the tectonically sheared shale matrix as well as in sandstone lenses, which were the basis for trap modeling. In either case, individual hydrocarbon accumulations are expected to be small because of the sheared and discontinuous nature of rock units observed in melanges of this type.

Some of the rocks of this play extend onshore and into State waters. These are included as a part of the Franciscan Oil and Gas play, which was defined but not quantitatively assessed by the USGS (Stanley, 1995a).

PETROLEUM GEOLOGIC CHARACTERISTICS

The Coastal belt of the Franciscan Complex is expected to be both source and reservoir for this play. Geochemical analysis shows the Coastal belt to have generally poor generative potential although a few local beds have fair to good potential (Crouch, Bachman, and Associates, Inc., 1987). However, seeps in the onshore area south of Eel River basin suggest it is a source locally. Reservoirs are expected to be relatively small, discontinuous sandstone lenses incorporated into a matrix of shale and mudstone from which they are sourced. The small pool sizes indicated by the discovery history are probably typical and are consistent with that model. There is no way to identify or predict the locations of larger sand bodies, given the lack of seismic signature, and there is no expectation for future advances in technology to increase this likelihood.

EXPLORATION

Two of the four offshore exploratory wells (OCS-P 0014 #1 and OCS-P 0019 #1) in the basin may have penetrated rocks of this play. The only indication of hydrocarbon reported was the presence of gilsonite (asphalt) veins in a core from the bottom of OCS-P 0019 #1 (Zieglar and Cassell, 1978). Rocks of the Coastal belt Franciscan south of the Eel River basin and petroliferous mudstones of Eocene to Miocene turbidite and melange sequences on the Olympic Peninsula, Washington, are considered to be equivalent to rocks of this play and the overlying Paleogene Sandstone play. Seeps exist in equivalent strata south of Eel River basin, and minor production has occurred since about 1860 (Stalder, 1914; Harmon, 1914; Vander Leck, 1921; MacGinitie, 1943). In the 1950's, about 350 bbl of high-gravity (46 °API) oil were produced in the Petrolia field south of the Eel River basin (California Division of Oil and Gas, 1960; 1982). From 1957 to 1962, about 12 Mbbl of high-gravity (38.9 °API) oil and about 6.5 MMcf of gas were produced in the Ocean City field near Grays Harbor, Washington (Braislin and others, 1971; McFarland, 1983; Palmer and Lingley, 1989).

RESOURCE ASSESSMENT

This play was not quantitatively assessed, although it is considered to be an important source of oil for the other plays in the basin. It is a conceptual play because no hydrocarbons have been detected within the play. There is evidence (outside of the Eel River basin) for hydrocarbon generation; however, the likelihood that accumulations of producible size exist is considered too low for this to be considered a viable play.